

## **Robust Project.**

### **Deliverables D.3.1 D.3.2.**

**D.3.1 Development of adequate specification for the measurement chains and procedures.**

**D.3.2 Development of validated procedures for the verification and calibration of data acquisition systems.**

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## 1 Introduction.

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This document contains the results of activities conducted in Task 3.1 and 3.2 of Robust project.

The basic purpose of these tasks is here reported:

**Task 3.1:** Development of adequate specification for the measurement chains and procedures.

**Task 3.2:** Development of validated procedures for the verification and calibration of data acquisition systems.

## 2 Task 3.1 Development of adequate specification for the measurement chains and procedures.

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This report contains different parts. In the first a the moving average technique, used to evaluate severity indices, is analysed. Results of this first phase are than applied to Round Robin activity.

### 2.1 *Moving average technique*

In this part of the document the influence of the moving average technique, required by Nchrp350 (1) and EN1317 (2) standards, on the PHD/ASI severity indices evaluation is studied. The moving average filters signals with an attenuation shape that does not preserve the energy information stored inside them and can modify indices working in a complete different way on frequencies that differ for few hertz. Some examples are reported showing that vibrations commonly present during safety barriers crash tests can be cancelled or not, depending on their frequency, by the moving average. Different accelerometer mountings for the same test could produce severity indices below or above the acceptance limits depending on the proper frequencies.

A modified procedure to evaluate ASI/PHD is here proposed using a standard filtering technique. Future research are needed to identify the proper cut-off frequency but some remarks are here reported to start a discussion. This procedure has been applied to several real signals to show the modification produced on ASI.

#### 2.1.1 *THE CENTER OF MASS*

A rigid body is a material system whose points have invariable distances to each other. On the contrary, the mutual distances between the points of a deformable body may vary during the motion.

For a set of material points, the centre of masse is the centre of a system of parallel vectors, of any direction, each heaving a length proportional to the mass of the point where the vector is applied. In other words it is the centroid of the masses. The center of mass is not a physical point, but just a location, or a geometrical point.

This definition applies both to rigid and deformable bodies. For a rigid body the centre of mass is a fixed point, whose location can be identified with the location of a material point. For a deformable body the centre of mass is not a fixed point; its location should be computed, at any time, as a weighted average of the positions of all the material points of the body.

For a body, rigid or deformable, the center of mass moves as a single point, having the mass of all the body, subject to the total force applied to the body. So, at any time, the acceleration of the centre of mass equals the resultant force applied to the body divided by the mass of the whole body.

For this last reason the acceleration of the centre of mass is so important.

## 2.1.2 MEASURE OF ACCELERATION

EN 1317-1, paragraph **7.4 Vehicle instrumentation** (normative), tells:

*The three sensors should be mounted on a common block and placed in point C close to the vehicle centre of gravity. .... The transducers, filters and recording channels shall comply with the frequency class specified in EN 1317-2 and EN 1317-3.*

Paragraph **8 Compensation for instrumentation displaced from the vehicle centre of gravity** (normative) tells:

*Vehicular accelerations are used in the assessment of test results through ASI, THIV and the flail space model. This requires that a set of accelerometers be placed at or close to the vehicle centre of mass.*

In Annex C (informative), paragraph **C1**, tells:

*In general during a collision there is an internal portion of the vehicle that remains more or less rigid, apart from structural vibration which are filtered out when the prescribed 60 Hz filter is applied.*

Unfortunately, experience has shown that there is no part of the vehicle that remains more or less rigid, at least from the point of view of acceleration measurements.

The 60 Hz filter is not prescribed in any part of EN 1317. EN 1317-2; instead paragraph **5.6 Vehicle instrumentation** tells:

*In accordance with EN 1317-1 the three accelerometers and the yaw rate sensor shall be mounted on a common block and placed as close to the vehicle centre of gravity as practical.*

*Acceleration and angular velocity transducers shall conform with ISO 6487, the frequency class being CFC 180.*

*CFC 60 may be used for plotting graphical results.*

Accelerometers cannot be attached to the centre of mass, for the simple reason that the centre of mass doesn't exist as a physical point. The acceleration of

the centre of mass cannot be measured, at least directly. In theory the acceleration of the centre of mass could be computed, from the accelerations measured in all the material points, as an average weighted with the masses of the points themselves. This is practically impossible.

For the above described reasons EN 1317 doesn't require the acceleration of the centre of mass, but the acceleration of a point close to the centre of mass. This requirement needs that the accelerometers remain close to the centre of gravity all the time during the collision (3).

During a collision the position of the accelerometers may vary in respect to the centre of mass for two basic reasons:

Centre of mass displacement respect to vehicle, due to large relative displacement of relevant masses (e.g. the engine).

Local vibrations of the point where the accelerometer is attached.

If vehicle deformation is not catastrophic, the first cause will move the centre of mass through small displacement. If accelerometer mounting has been well designed also the second cause will have small effect, in terms of relative displacement of the accelerometer.

A first question could be: how small is a *small displacement*? In a crash 1 mm is certainly a small displacement, and there is no doubt that a part of the vehicle that undergoes deflections of this order of magnitude can be considered *a portion of the vehicle that remains more or less rigid*, in the sense of Annex C of EN 1317-1. The effect of such small displacement on measured acceleration will be insignificant, if it is static.

But even a small oscillatory displacement, if the frequency is high enough, may have a strong effect on acceleration.

### 2.1.3 ACCELERATION IN VIBRATIONS

A point having a purely oscillatory motion, with a frequency  $f$  and a displacement amplitude  $S$ <sup>1</sup>, has an oscillatory acceleration, with the same frequency, and an amplitude  $A = S \times (2\pi f)^2$ . If  $S$  is measured in meters and we want the acceleration  $A$  in  $g$  units ( $9.81 \text{ ms}^{-2}$ ),  $A = S \times (2\pi f)^2 / 9.81$ . So, if the small oscillatory displacement is  $S = 1 \text{ mm} = 0.001 \text{ m}$ , for different frequencies we have:

Frequency $f$ [Hz]	10	20	30	40	50	60	70	80
Displacement $S$ [m]	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
$A = S \times (2\pi f)^2 / 9.81$ [g]	0.402	1.609	3.619	6.439	10.061	14.488	19.719	25.756

Tab. 1 – Acceleration of 1 mm oscillation at different frequencies

<sup>1</sup> This means that the point is oscillating between the distances  $+S$  and  $-S$  from its equilibrium position, and viceversa,  $f$  times per second.

The point where the accelerometers are attached undergo local oscillations, which may easily exceed the displacement amplitude of 1 mm. This affects the measures from the accelerometers by a large disturbance that is not related to the acceleration experienced by the occupants.

In fact, in all the biomechanical measurements, obtained with the use of instrumented dummies, there are no significant frequencies above 10 Hz.

#### 2.1.4 LOW-PASS FILTERING

In principle the measure of a time dependent quantity is a continuous history. The digital measure of a time dependent quantity is a series of samples, i.e. of numbers taken at equal time intervals. We refer to this series as a time series. A continuous history is also called a continuous time series. Any time series can be expressed as the sum of several purely sinusoidal components of different frequencies.

A low-pass filter is a device that, applied to a time series, produces another time series, having the components above a certain frequency eliminated or strongly attenuated. The gain of a filter is the ratio of the output to a sinusoidal input, plotted vs frequency. The gain of a low-pass filter should be equal to unity from 0 hz to a frequency where the filter starts working, and then gradually decrease for higher frequencies (4).

A digital filter is an algorithm capable of filtering digital time series.

#### 2.1.5 THE MOVING AVERAGE

EN 1317-1 tells that for computing ASI the three components of the accelerations must be averaged over a moving time interval of 50 ms. This operation, often referred as *moving average over 50 ms*, transforms a time series in another time series with a different frequency content, like a filter.

The effect of the moving average can be easily computed for a purely sinusoidal series like  $a(t) = A \sin(2\pi ft)$ , where  $A$  is the amplitude and  $f$  is the frequency. If the number of samples taken in the averaging interval  $\delta$  is high enough, the summation required by the averaging process can be substituted by an integral, and the result of the process is:

$$\bar{a} = \frac{1}{\delta} \int_{t-\delta/2}^{t+\delta/2} a d\tau = \frac{1}{\delta} \int_{t-\delta/2}^{t+\delta/2} A \sin(2\pi f\tau) d\tau = -\frac{1}{2\pi f} \left[ A \cos(2\pi f\tau) \right]_{t-\delta/2}^{t+\delta/2} = A \frac{\sin(\pi f \delta)}{\pi f \delta} \sin(2\pi ft)$$

Eq. 1

then the *gain* of the moving average, i.e. the ratio of the output to the input is

$$G(f) = \bar{a}/a = \sin(\pi f \delta)/\pi f \delta$$

Eq. 2

This has been plotted in figure 1 for  $\delta = 50$  ms. Figure 2 reports the same result but using an attenuation representation.

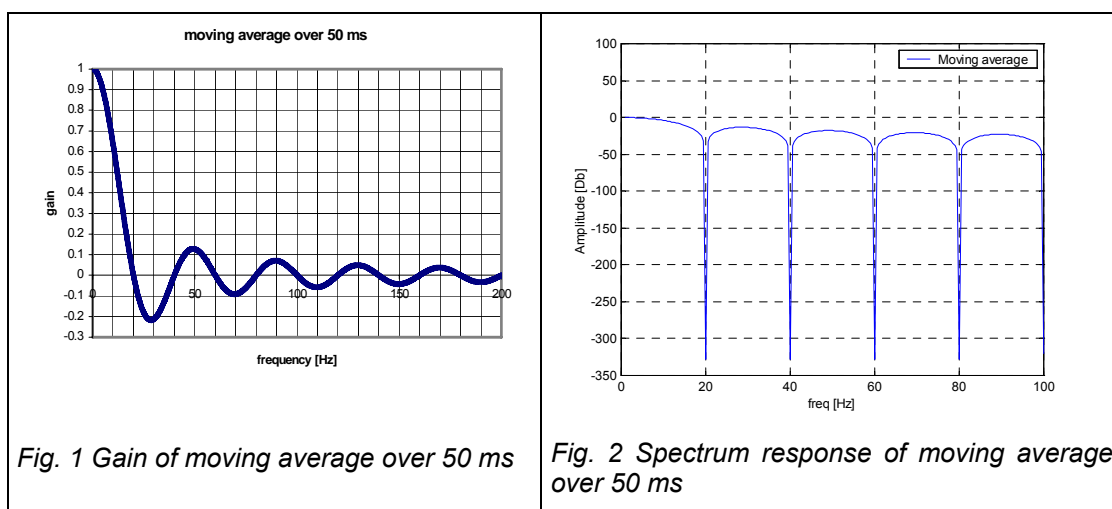
Fig. 1 Fig. 2 show that moving average, seen as a filter, has a very poor gain or attenuation performance. The moving average gain is 1 only at 0 Hz, and starts modifying signals immediately after; at 10 Hz it has already decreased to 0.63; at 20 Hz it is exactly 0. Then, at 30 Hz it rises to about -0.22, goes to zero at 40 Hz, and so on. At 130 Hz it is still above 0.05. The negative gains corresponds to a phase lag of  $\pi$  radians, hence a time lag of  $2/f$ .

The moving average is than a imperfect filter because:

The gain modifies signals at very low frequencies.

The gain decreases too slowly with frequency: the disturbance of high frequency oscillations remains to high

The suppression of some frequencies and the negative gain for some others distorts the function and alters its information content in an uncontrolled way.



The following Fig. 3 Fig. 4 show the gain of a standard low-pass filter, a Butterworth phaseless 2-pole forward-backward (4) filter with a cut-off frequency of 10 Hz, cut-off being the frequency where the magnitude response of the filter is  $1/\sqrt{2}=0.707$ . This kind of filter produces the same effect as a standard 4-pole Butterworth filter but does not present phase shift problems. It is important to underline the differences between the behaviour of moving average and filtering here described.

The filter gain does not affect lower frequencies, it is always positive and, changing the frequency, goes to zero smoothly, being less than 5% above 30 Hz. On the contrary the moving average gain (Figures 1-2) affects also signals at very low frequencies, it has negative parts and its amplitude has discontinuities every 20hz.

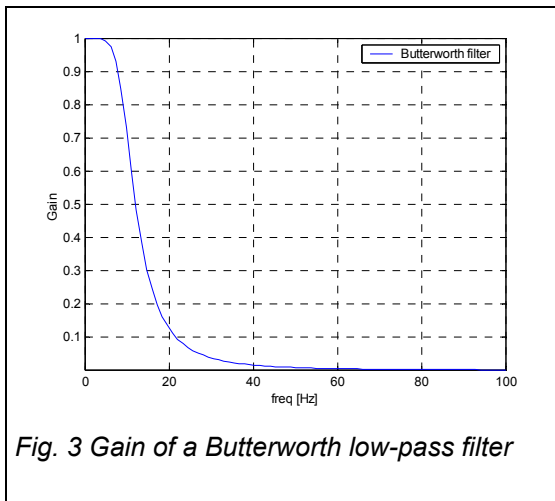


Fig. 3 Gain of a Butterworth low-pass filter

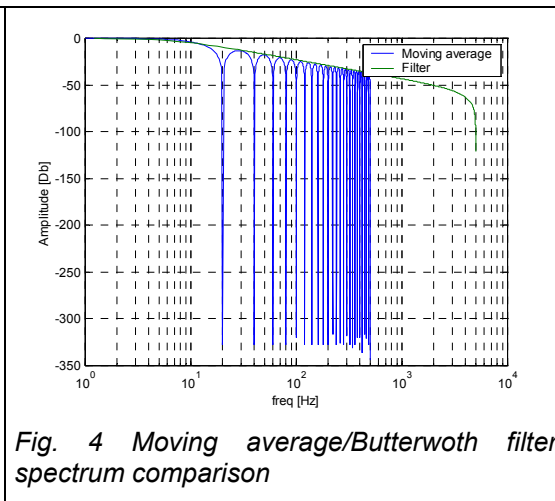


Fig. 4 Moving average/Butterworth filter spectrum comparison

To better illustrate the influence of moving average technique on real signals, velocity time histories have been obtained integrating real crash test accelerometer signals. From Fig. 5 can be seen that the moving average does not maintain the energy giving a complete wrong velocity time history and the difference between the velocity obtained from moving averages and unfiltered signals can vary with different signals. In these figures these velocities have been also compared with velocities obtained on the same signals filtered with the Butterworth filter described above.

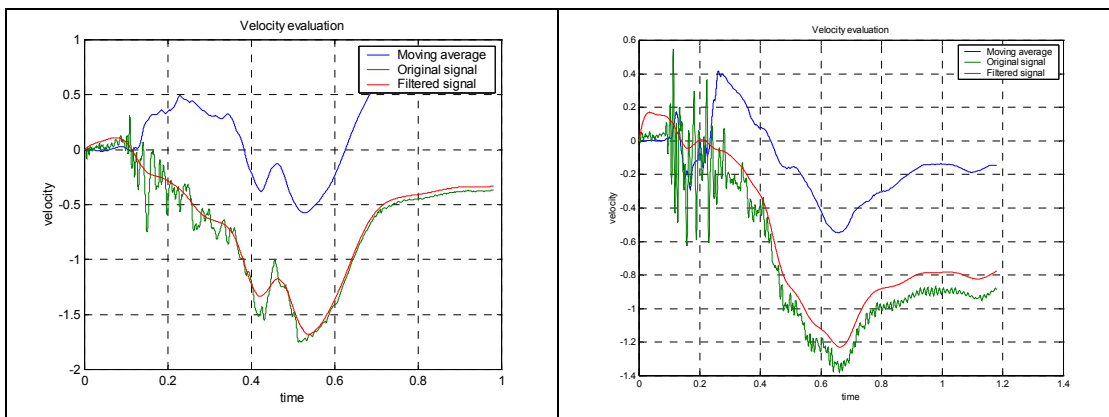


Fig. 5 Comparison between velocity obtained from original signals, filtered signals and signals modified by a 50 ms moving average.

From the above described reasons can be concluded that the moving average technique, seen as a filter, has poor behaviour and can also randomly (depending on the spectrum of the real signal) modify the energy (in this case velocity) described by the original signals.

**2.1.6 LOCAL VIBRATIONS IN REAL BARRIER CERTIFICATION TESTS.**

To evaluate if real signals acquired during standard certification tests for safety barriers contain also vibration as described in the first paragraphs, signals obtained from certification tests have been analysed.



Fig. 6 shows the lateral component of the acceleration, as measured in two TB 11 (900 kg 100 km/h 20°) tests, unfiltered and filtered with a CFC 60 filter. Strong oscillations are present with peaks up to 30 g and -25 g. Negative accelerations are clear indication of local oscillations. In fact, a true negative acceleration of the centre of mass would indicate a negative force, i.e. a pull toward the barrier, that for -25 g would be  $-25 \times 9.81 \times 920 = -225.6$  kN that is clearly impossible.

Filtering with a CFC60 has no effect in removing the noise from local vibration. CFC 180 filtering would be less effective because it has an attenuation shape that is shifted at higher frequencies and cannot modify the vibrations that are located below 100 hz. Noise removal requires a much lower cut-off frequency, as it will be discussed in the following.

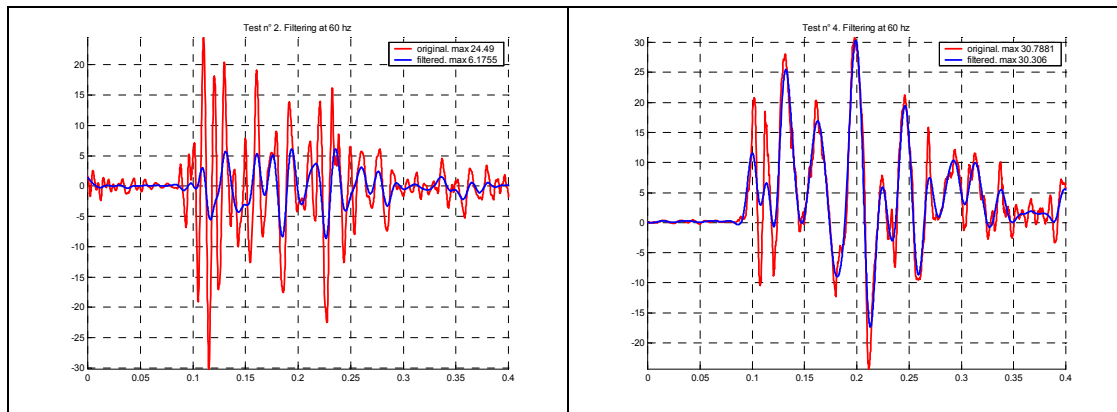


Fig. 6 Lateral acceleration [g] from TB 11 tests

### 2.1.7 EFFECT OF OSCILLATIONS ON ASI VALUE.

To illustrate the effect on ASI of local oscillations, we have considered only transverse acceleration and applied the following formula:

$$ASI = \max \left( \sqrt{(\bar{a}_x/12)^2 + (\bar{a}_y/9)^2 + (\bar{a}_z/10)^2} \right) = \max \left( \sqrt{(\bar{a}_y/9)^2} \right) = \max |\bar{a}_y/9|$$

Eq. 3

Then the effect on ASI of such local oscillation is an increment:

$$\Delta ASI = AG/9 = 0.001(2\pi f)^2 |\sin(\pi f \delta)/9\pi f \delta|$$

Eq. 4

This effect has been plotted in Fig. 7. Even this small oscillation has a remarkable effect: at 30 Hz it gives an increment close to 0.1, at 40 Hz 0.0, at 50 Hz 0.14, at 60 Hz 0.0, and so on. Such effect should be removed because it is erratic and can strongly modify the ASI value. In Fig. 8 the influence on ASI value of different noise amplitudes is reported.

These increments must be compared with the threshold values included in the standards. European EN1317 part 2 describes two levels for ASI a first level with a value  $<1.0$  and a second level with  $1.0 < ASI < 1.4$ . Can be seen that vibrations of 1mm, depending on the frequency, could be able to modify ASI value in such a way that the test will fail.

Fig. 8 shows how different amplitudes at different frequencies can modify the ASI value.

A modified ASI algorithm has been then developed using a forward-backward 2 pole Butterworth (5-6) instead of the moving average.

To remove the noise, which has neither physical meaning nor effect on the real severity, the best solution is to substitute the moving average, in the procedure to compute ASI and PHD, with an appropriate low-pass filtering. The proposal is to use Butterworth phaseless 2-pole forward-backward filter with a cut-off frequency to be identified.

A first application of this method has been conducted with a cut-off frequency of 10hz. The effect of the same oscillation described above, on the modified ASI is reported in Fig. 9.

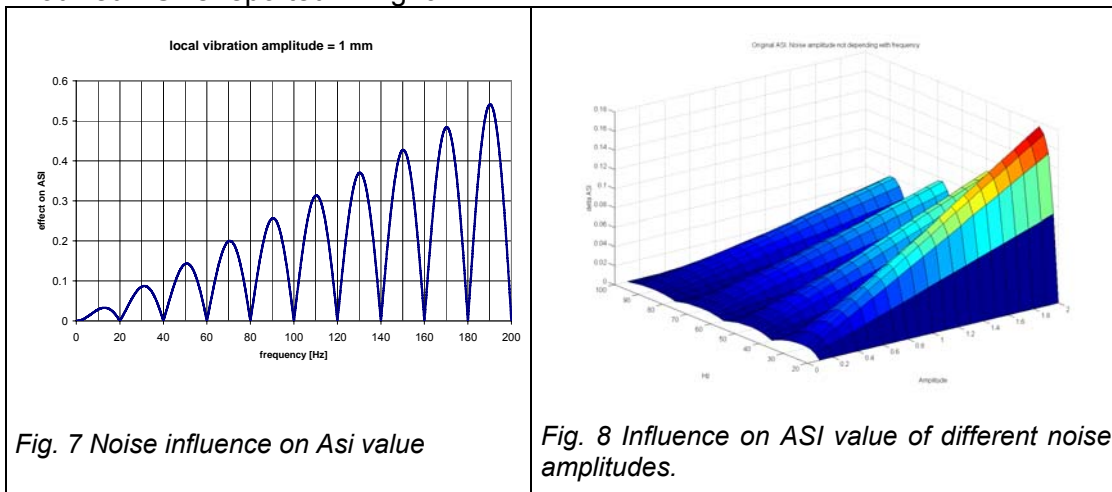


Fig. 7 Noise influence on Asi value

Fig. 8 Influence on ASI value of different noise amplitudes.

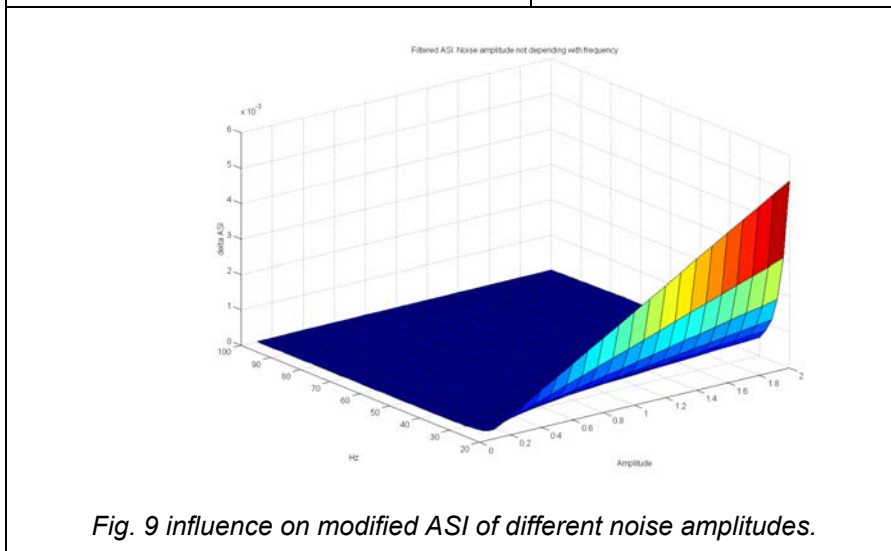


Fig. 9 influence on modified ASI of different noise amplitudes.

The modified ASI formula has been then applied to several real acceleration time-histories to illustrate the influence on the final real results. Using a 10 hz cut-off frequency the modified ASI value shows an average decrease of 0.15. Applying the

same procedure on the results of the European Round Robin Program (same car against same rigid barrier in 6 different labs), the scatter between labs has been reduced by a factor of three going from 0.33 to 0.10. (ASI unit).

The same approach has been applied to certification tests where the ASI vale has been evaluated with a standard procedure or using the above describe filter. In Fig. 10 and in Tab. 2 the ASI/ modified ASI time histories are reported as well as the maximum ASI values.

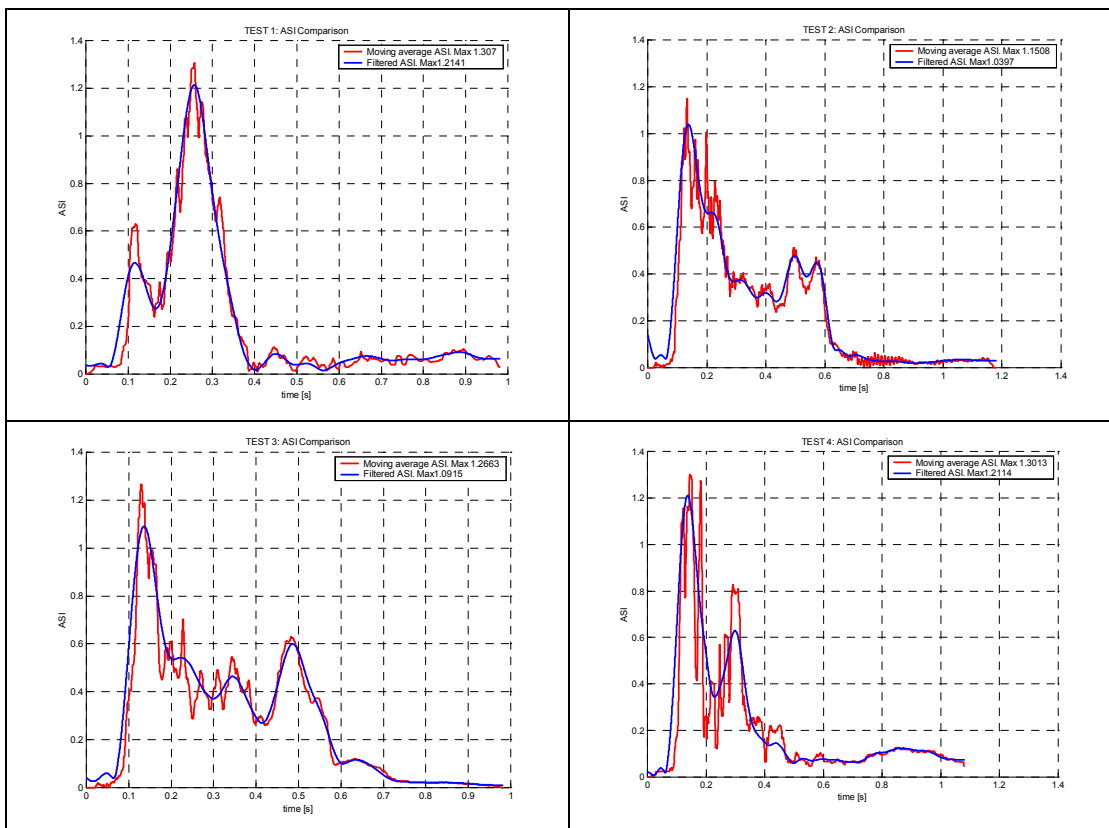


Fig. 10 Original ASI/modified ASI

Test n°	Max ASI (moving average)	Max ASI (filtered)
1	1.31	1.21
2	1.15	1.04
3	1.27	1.09
4	1.30	1.21

Tab. 2

### 2.1.8 EFFECT ON PHD

PHD is also computed through a moving average using a window of 10 ms, for this reason the same problem described for ASI is applicable to PHD evaluation at higher frequencies.

### 2.1.9 MODIFIED ASI: CUT-OFF FREQUENCY.

To identify the proper cut-off frequency to be used for the proposed modification of ASI formula some consideration have been made.

The following figures Fig. 11 to Fig. 14 show the effect of different low-pass filtering on the acceleration considered figure 3. With 20 Hz filtering, negative accelerations are still present; 15 to 10 Hz give reasonable curves, 12.5 hz being possibly the best. These filters have been designed using the same algorithm used for CFC filters but with different cut-off frequencies that are nominally 124.65 hz for CFC60 and 373.95 hz for CFC180. Therefore our 15 hz filter could correspond to a CFC 7.22

In Fig. 15 and Tab. 3 the modified ASI value is reported with respect to different cut-off frequency. Having shown that the final ASI value depends on the chosen cut-off frequency, a modification of the thresholds limits accepted by the standards should be also taken into account.

The choice of the right cut-off frequency needs further investigations but a first point of discussion can be found in Fig. 16 where spectrums of vehicle CG and Hybrid III dummy head accelerometers are reported for a Tb11 test (900 kg 100 km/h 20°).

Can be noted that dummy frequencies are below 10 hz but vehicle frequencies have components at much higher values that, maybe, are not related with the safety of the occupants. The information obtained from the use of instrumented dummies during certification tests could be used to identify the proper cut-off frequency as the one that limits the real frequencies transmitted by the structure to the occupants.

Must be also stated that the proposed method would not be used to reconstruct the displacement time histories of the vehicle or to study his structural behaviour, but only to obtain severity indices not depending on local information that could affect the final result.

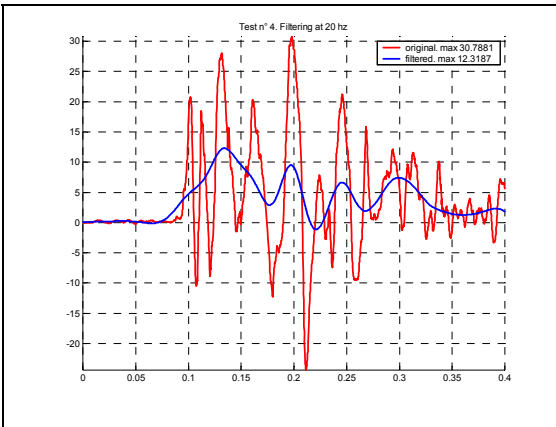


Fig. 11 Filtering at 20 Hz

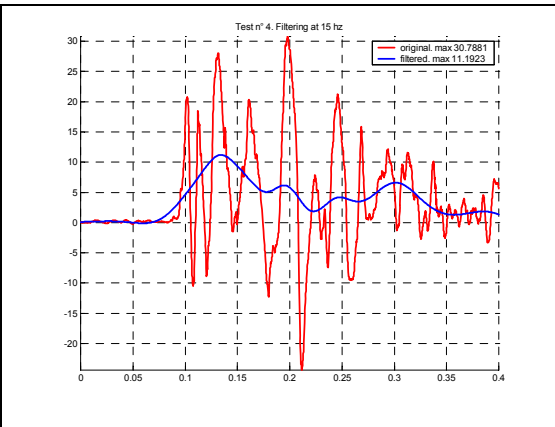


Fig. 12 Filtering at 15 Hz

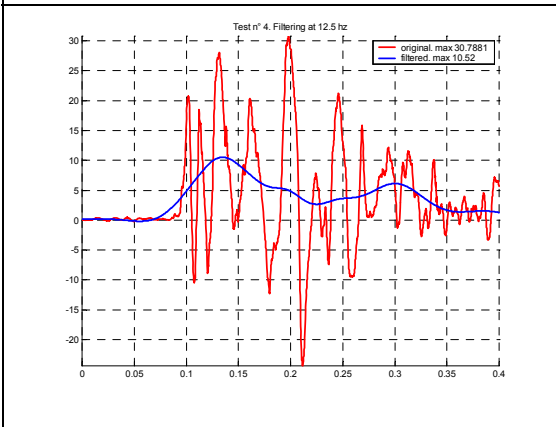


Fig. 13 Filtering at 12.5 Hz

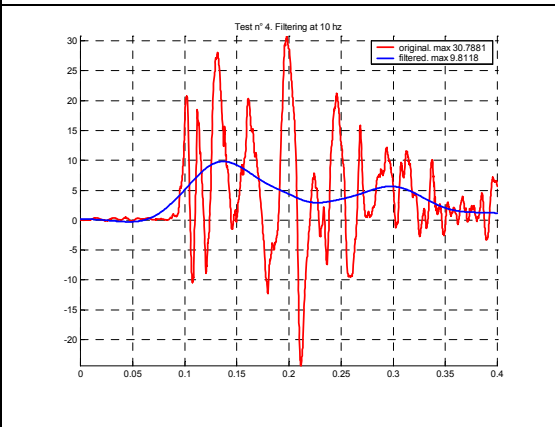


Fig. 14 Filtering at 10 Hz

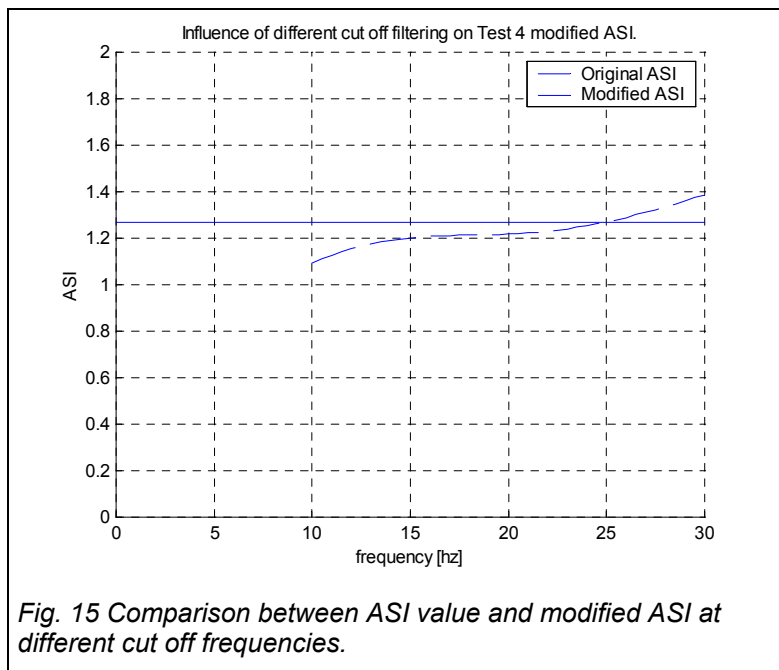


Fig. 15 Comparison between ASI value and modified ASI at different cut off frequencies.

hz	Modified ASI
10.0	1.0915
15.0	1.2009
20.0	1.2181

25.0	1.2705
30.0	1.3876

Tab. 3 Comparison between ASI value and modified ASI at different cut off frequencies.

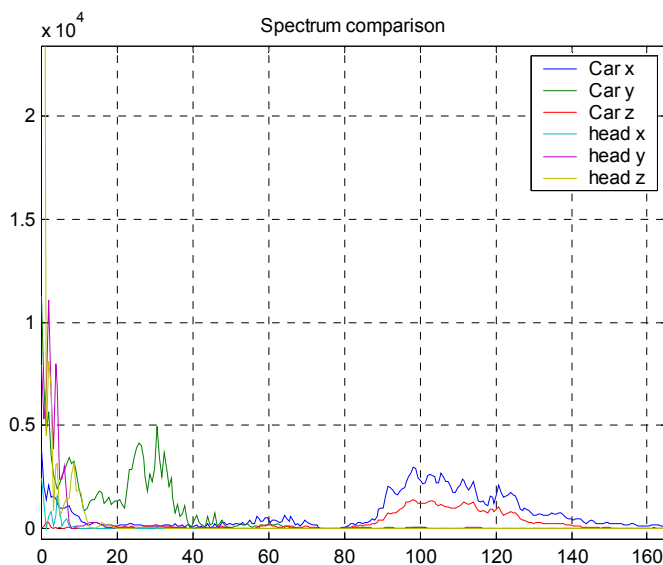


Fig. 16 Spectrum comparison. Dummy and car accelerations.

**2.1.10 CONCLUDING REMARKS ON MOVING AVERAGE.**

The mechanical noise affecting acceleration measures, which has neither physical meaning nor effect on the real severity, shall be removed for the evaluation of severity indices. Moving average shows a not reliable behaviour modifying signals cancelling some frequencies but maintaining others.

A modification has been proposed substituting the moving average, in the procedure to compute ASI and PHD, with an appropriate low-pass filtering. For ASI and PHD an appropriate filter could be a 4 poles phaseless Butterworth. Further investigations are needed to identify the appropriate cut off frequencies. These investigations will be faced during a European sponsored project, “Robust- Road Upgrade of Standards”, where the accelerometers mounting as well as the severity indices obtained from dummy measurement will be studied.

An alternative but less desirable proposal is to filter the acceleration components with a 4 poles phaseless Butterworth with cut-off at 15 to 17.5 Hz, and leave the moving average in the procedure for ASI. This problem does not avoid the described defects of the moving average but can mitigate them through the use of the filtering.

## 2.2 Round Robin Activity.

Round Robin represent a series of tests carried in different European Laboratories to evaluate the procedures used to obtain certification results, as severity indices and acceleration time histories, according to EN 1317.

This activity has been divided in two parts:

Round Robin 1: TB11 tests, same new car (Peugeot 106), same concrete rigid barrier in all the labs. Only, transducers, data acquisition system and software is different.

Round Robin 2: TB11 tests, different cars (each lab uses own standard car), same concrete rigid barrier.

The first part is to evaluate the scatter between nominally same experiments. The second part is to evaluate the scatter arising from tests performed in general according EN1317.

To this project the following test houses have participated:

TRL	UK
LIER	France
CIDAUT	Spain
HUT	Finland
AUTOSTRAD	Italy
BAST	Germany

### 2.2.1 ROUND ROBIN I.

In the following table severity indices obtained from the Round Robin 1 are reported. On the main diagonal severity is evaluated by each test house on its results. Outside the diagonal the evaluation of severity is performed by the other test houses on the same signal, this part is to evaluate the influence of software on the severity indices evaluation. The table is not complete due to large differences between labs.

		Test performed by														
		Hut			Lier			Cidaut			TRL			Auto		
E v a l u a t e d b y		asi	thiv	phd	asi	thiv	phd	asi	thiv	phd	asi	thiv	phd	asi	thiv	phd
		Hut	asi	1.83			1.84			1.91			1.87			
		thiv		32.40			31.40			32.80			33.80			
		phd			17.70			11.90			11.00			18.27		
	Lier	asi	1.79			1.85			1.88			1.85				
		thiv		31.44			32.57			33.29			32.63			
		phd			17.22			12.26			10.78			15.00		
	Cidaut	asi	1.81			1.84			1.91							
		thiv		32.78			32.40			34.20						
		phd			17.74			11.95			11.40					
	Trl	asi	1.87			1.85			1.86			1.84				
		thiv		33.67			32.42			32.82			32.40			
		phd			18.27			13.72			10.94			15.24		
	Auto	asi												2.17		
		thiv													31.05	
		phd														12.93

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Tab. 4 Round Robin 1 results

A first analysis show a large scatter between labs and strong differences between different indices evaluation of the same signals. To better understand this problem a first analysis found as a keypoint the offset evaluation that can produce strong influences on THIV value and medium influences on ASI and PHD.

### 2.2.1.1 Offset removal.

A first origin of differences has been found during offset removal procedures. Offset is usually evaluated obtaining the mean value of that channel for some milliseconds before the impact. The number of milliseconds used as well as the precise impacting point sample evaluation can produce different offset results on the same signal. Moreover acceleration time histories just before the impact can contain oscillations transmitted from ground and (mainly for pushed or pulled car systems) the release of the car induces movements of the vehicle that can influence offset evaluation.

For this reason the evaluation of zero-level could be performed just before the test but with the vehicle stationary. However, applying this procedure would on the other hand increase the risk of other sources of errors in measurements. The main reason is that measuring over longer periods of time (i.e. minutes) causes drift phenomena, which means that during the vehicle motion prior to the impact the measured acceleration values may also deviate from the actual ones. Therefore, a deep study of the effect of evaluating zero-level before the test but with the vehicle stationary should be completed before such procedure is applied.

In the following figure the acceleration history obtained during a Round Robin test just before the impact is shown.

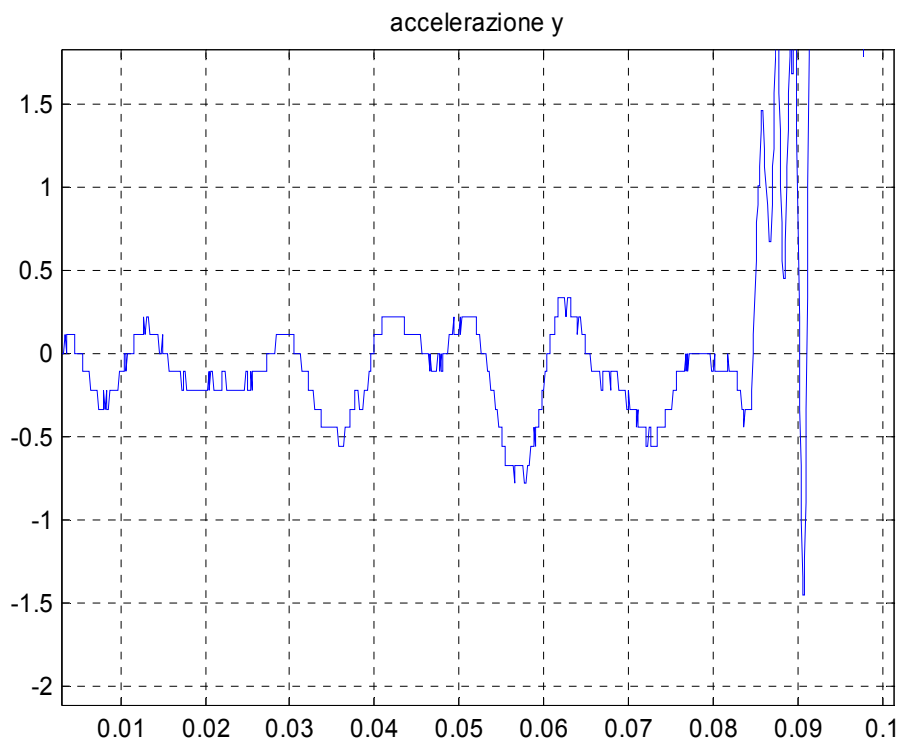


Fig. 17 Acceleration signal just before the impact.



Can be seen that, in this case, oscillation with amplitude of about 1 g are present before the impact being the mean value zero but can be understood that a different offset window or a real vehicle acceleration can strongly influence the output. As an example a different offset evaluation of .5 g on each channel can produce a delta in ASI of about 0.1, in THIV (for the Round robin impact where time of flight is about 0.07 s) 1.74 km/h

### 2.2.1.2 Software influence

To investigate the influence of different software a benchmark file has been produced where the different offset evaluation procedures would not generate influences. This signal is simply one of the original signals where the impacting point has been defined and all data before this point are equal to 0. With this file the influence of offset removal has been avoided. In the following table the results of this activity is reported.

	ASI	t (s)	THIV	t (s)	PHD	t (s)
Cidaut	1.84					
			32.43	0.0766		
					12.15	0.1369
Hut	1.84	0.0097				
			32.45	0.0766		
					11.88	0.1370
Lier	1.84	0.0099				
			32.49	0.0767		
					12.15	0.1370
Trl	1.84	0.1148				
			32.43	0.1566		
					13.69	0.2220
TRAP	1.84	0.0098				
			32.4	0.0779		
					11.9	0.1370

Tab. 5 Results of benchmark file.

Can be seen that the different software used evaluate indices with scatter could be avoided. Conclusion to this point is that a validated and common software should be used to evaluate severity indices.

### 2.2.1.3 Differences between tests.

To investigate the real differences between tests two activities have been conducted:

Analysis of video and still images

Analysis of data with a common software and different filtering techniques.

#### 2.2.1.3.1 Analysis of video and still images.

Observing video, cars and still images some points must be considered. Cars where nominally the same but with slight differences:

n° of doors (2/4)

steering position (left / right)  
 engine power (i.e. weight)  
 tire conditions

These differences can produce some of the final differences found also in for the car deformation.

During the tests tire/ground conditions where not the same (temperature, wet/dry asphalt). A lower tire friction has been observed for test houses with higher Phd values.

### 2.2.1.3.2 Analysis of data with a common software and different filtering techniques.

Starting point is Tab. 4. That is condensed in Tab. 6 with only severity indices computed by the labs. To evaluate the real differences between signals different activities have been conducted. First is the ASI evaluation on all the results using the same software (developed at Politecnico). This evaluation permit to add a column to Tab. 6 containing this data.

<b>Hut</b>	<b>asi</b>	<b>1.83</b>
<b>Lier</b>	<b>asi</b>	<b>1.85</b>
<b>Cidaut</b>	<b>asi</b>	<b>1.91</b>
<b>Trl</b>	<b>asi</b>	<b>1.84</b>
<b>Auto</b>	<b>asi</b>	<b>2.17</b>
<b>Mean</b>		<b>1.92</b>
<b>Max</b>	<b>Asi unit</b>	<b>0.25</b>
<b>Min</b>	<b>Asi unit</b>	<b>-0.09</b>
<b>Max</b>	<b>%</b>	<b>13.02</b>
<b>Min</b>	<b>%</b>	<b>-4.69</b>

Tab. 6 Original ASI values

		Original	ASI Polimi
<b>Hut</b>	<b>asi</b>	<b>1.83</b>	<b>1.83</b>
<b>Lier</b>	<b>asi</b>	<b>1.85</b>	<b>1.84</b>
<b>Cidaut</b>	<b>asi</b>	<b>1.91</b>	<b>1.92</b>
<b>Trl</b>	<b>asi</b>	<b>1.84</b>	<b>1.82</b>
<b>Auto</b>	<b>asi</b>	<b>2.17</b>	<b>2.17</b>
<b>Mean</b>		<b>1.92</b>	<b>1.92</b>
<b>Max</b>	<b>Asi unit</b>	<b>0.25</b>	<b>0.25</b>
<b>Min</b>	<b>Asi unit</b>	<b>-0.09</b>	<b>-0.10</b>
<b>Max</b>	<b>%</b>	<b>13.02</b>	<b>13.26</b>
<b>Min</b>	<b>%</b>	<b>-4.69</b>	<b>-5.01</b>

Tab. 7 Politecnico evaluation of ASI

Signals obtained from different laboratories contains oscillation at different frequencies. In the following figure the comparison between y component of different labs with different filtering frequencies are reported.

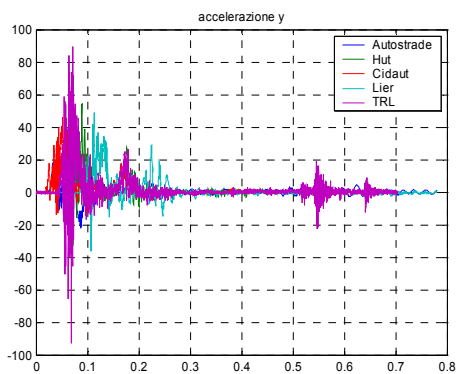


Fig. 18 Original signals

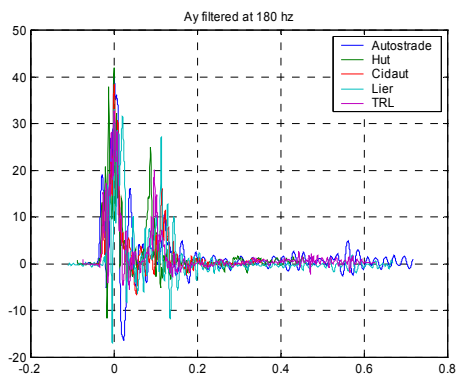


Fig. 19 180 hz

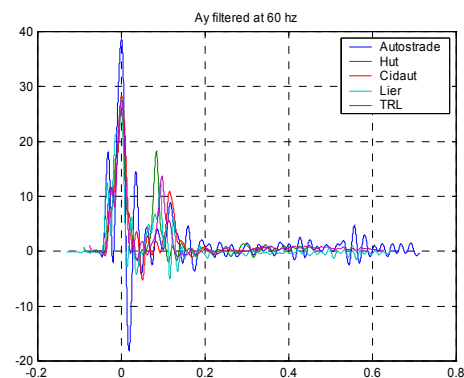


Fig. 20 60 hz

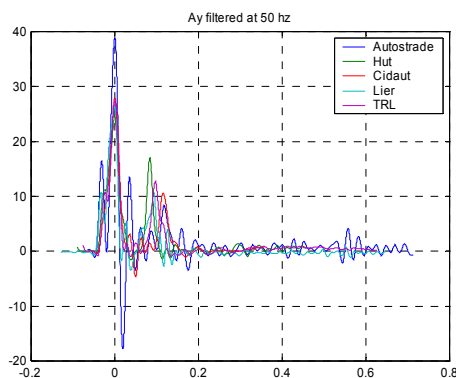


Fig. 21 50 hz

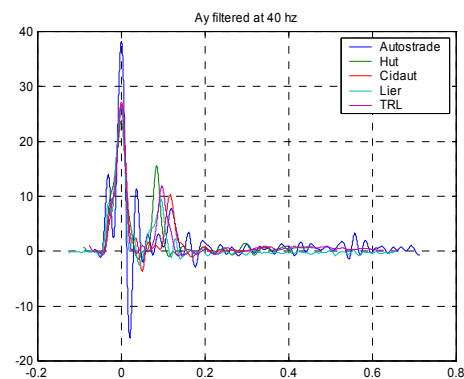


Fig. 22 40 hz

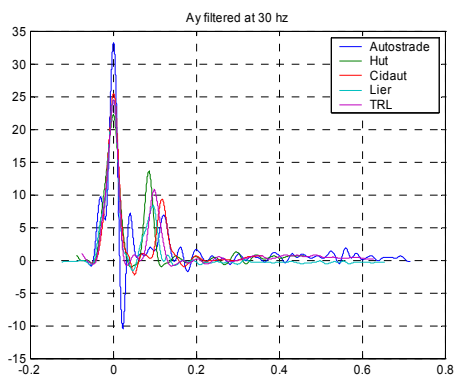
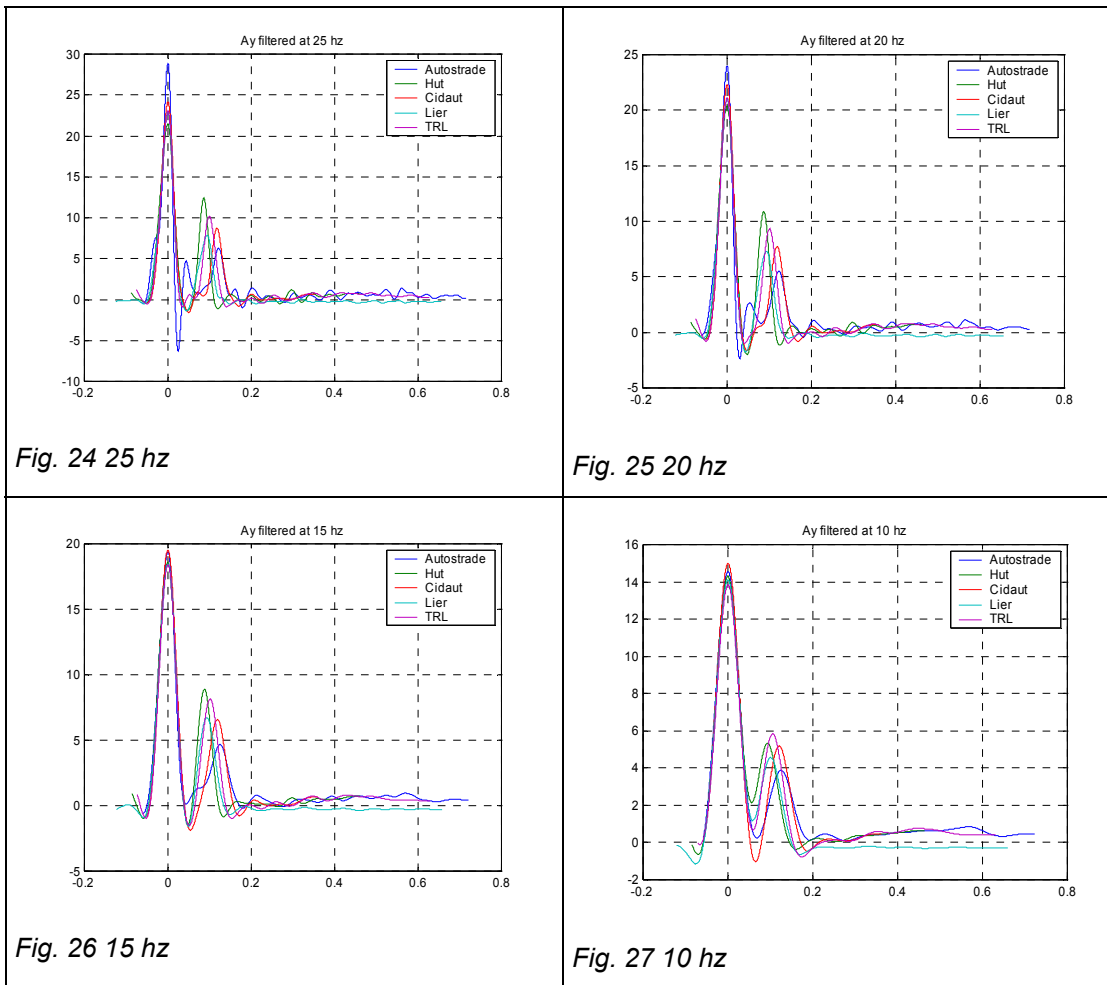


Fig. 23 30 hz



Can be seen from the previous figures that signals contains vibrations that create completely different time histories. Filtering signals the situation changes and a good comparison between tests can be found at a filtering frequency of about 10 hz.

According to the first part of this document (influence of moving average) to reduce the scatter ASI values have been computed with a filtering technique instead of the moving average creating a new column for Tab. 7 .

		Original ASI	ASI Polimi	ASI 10 hz
<b>Hut</b>	<b>asi</b>	<b>1.83</b>	<b>1.83</b>	<b>1.72</b>
<b>Lier</b>	<b>asi</b>	<b>1.85</b>	<b>1.84</b>	<b>1.69</b>
<b>Cidaut</b>	<b>asi</b>	<b>1.91</b>	<b>1.92</b>	<b>1.83</b>
<b>Trl</b>	<b>asi</b>	<b>1.84</b>	<b>1.82</b>	<b>1.68</b>
<b>Auto</b>	<b>asi</b>	<b>2.17</b>	<b>2.17</b>	<b>1.80</b>
<b>Mean</b>		<b>1.92</b>	<b>1.92</b>	<b>1.74</b>
<b>Max</b>	<b>Asi unit</b>	<b>0.25</b>	<b>0.25</b>	<b>0.09</b>
<b>Min</b>	<b>Asi unit</b>	<b>-0.09</b>	<b>-0.10</b>	<b>-0.06</b>
<b>Max</b>	<b>%</b>	<b>13.02</b>	<b>13.26</b>	<b>4.93</b>
<b>Min</b>	<b>%</b>	<b>-4.69</b>	<b>-5.01</b>	<b>-3.67</b>

Tab. 8 ASI evaluation with filters

From the previous table can be seen that filtering technique decreased scatter from 13.02 % to 4.93 %.

This result has been also applied to the same data where Autostrade values has been neglected (due to their strong deviation) with the following results:

		Original	ASI Polimi	ASI hz	10
<b>Hut</b>	<b>asi</b>	<b>1.83</b>	<b>1.83</b>	<b>1.72</b>	
<b>Lier</b>	<b>asi</b>	<b>1.85</b>	<b>1.84</b>	<b>1.69</b>	
<b>Cidaut</b>	<b>asi</b>	<b>1.91</b>	<b>1.92</b>	<b>1.83</b>	
<b>Trl</b>	<b>asi</b>	<b>1.84</b>	<b>1.82</b>	<b>1.68</b>	
<b>Mean</b>		<b>1.86</b>	<b>1.85</b>	<b>1.73</b>	
<b>Max</b>	<b>Asi unit</b>	<b>0.05</b>	<b>0.07</b>	<b>0.10</b>	
<b>Min</b>	<b>Asi unit</b>	<b>-0.03</b>	<b>-0.03</b>	<b>-0.05</b>	
<b>Max</b>	<b>%</b>	<b>2.83</b>	<b>3.64</b>	<b>5.78</b>	
<b>Min</b>	<b>%</b>	<b>-1.48</b>	<b>-1.75</b>	<b>-2.89</b>	

Tab. 9 4 lab evaluation

### 2.2.2 RECOMMENDATIONS.

Has been demonstrated that offset evaluation and removal has a strong influence on severity indices evaluation. To avoid these influences zero level of signals should be evaluated just before the test with the vehicle stationary.

A common software between European Laboratories should be used to evaluate severity indices.

Tire/ground condition should better described by EN1317.

Round Robin first series of tests showed a quite remarkable scatter that can be seen from different contribution:

1. Different car details.
2. Different tire condition.
3. Different impact conditions (speed, angle).
4. Data acquisition system (transducers, mounting).
5. Data filtering and severity indices evaluation.

For each of the above point some consideration must be addressed:

1,2 For both these points the comment is that the desirable condition should be to have the exactly the same car with the same tire but, having received these donated vehicles we must only accept and record these differences.

3 Impact condition for different labs were always inside the EN1317 prescription and, for this reason, we cannot ask for modification but only record the better we can the information available.

4 We have not yet recorded the transducers differences between the labs but is the feeling that all the transducers used are suitable for the purpose of the test, with the appropriate frequency and range performances. Some comments must be done regarding the mounting.

- Standard mounting is obtained with steel or aluminium structures used to install gyro meter and accelerometers near the vehicle CG.
- These structures, even if built to be enough stiff, can introduce, due to their weight, local inertia loads in the lower part of the vehicle that can excite some natural frequencies.
- There is no need and no indication in EN1317 to place Gyro meter near to vehicle CG.
- Acceleration spectrum response is quite different between the laboratories even if the lower part of the vehicle should be the same.

From the above points some remarks on the mounting can be stressed.

Gyro meter should not be installed on the mounting block used for accelerometers to avoid the increase of inertia loads on the vehicle floor. The gyro measure is not affected by the position and this transducer can be mounted in a stiffer vehicle zone.

The mounting block should be very light to avoid inertia loads but also very stiff to avoid local vibration. One possible solution is to use composite structures to obtain this result and Politecnico would try to build some of these blocks to be used during the WP4 activity.

Regarding data acquisition system our recommendation is to use a digital system with at least:

12 bit resolution

10 kHz sampling frequency

.2 pre trigger samples

CAC appropriate for the measure (avoid signal saturation but enough useful information, typically CAC not higher than 100 g)

Anti aliasing filters are recommended if undamped accelerometers are used.

Zero evaluation before the vehicle is accelerated.

5 For this point the need of having one common software has been already focused and, for the WP4 activity, our suggestion is to use Trap.

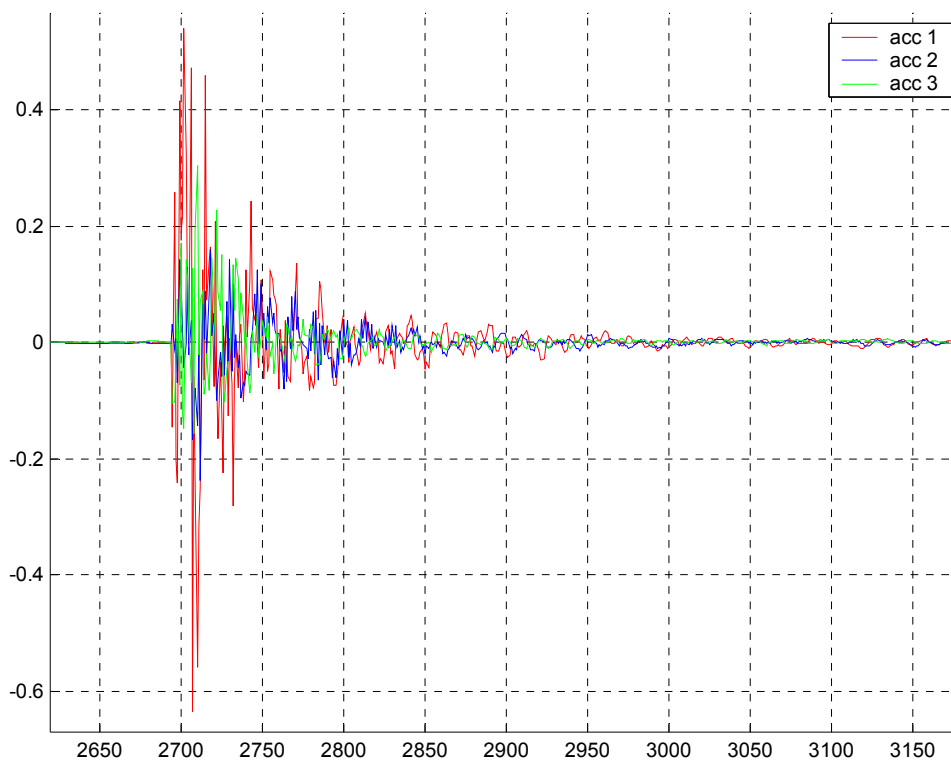
### **2.3 Mounting block mass influence.**

To evaluate the influence of the accelerometers mounting block on the severity indices evaluation a first activity has been conducted measuring the first natural frequency of the floor structure. Cars are usually designed to have this frequency above 30 hz for comfort and noise requirements but, the presence of the mounting block mass, could modify this frequency and this modification could influences the severity indices measure.

The first activity conducted to investigate this problem started in Lier on may 2003. The mounting block installed on a Round Robin car has been instrumented with modal analysis standard piezoelectric accelerometers. These accelerometers can measure frequencies up to 50 kHz and have a range capable to observe oscillations introduced with small impacts. A triaxial accelerometers has been

mounted on the top of this mounting block and the structure has been impacted with an hammer in different directions to measure the free vibration of the structure. Being the aim of this activity a spectrum evaluation the hammer has not been instrumented.

During the test about 30 impacts has been acquired. A typical output is reported in the following figure.



*Fig. 28*

From these signals, using a FFT technique, the spectrum (Fig. 29 ) has been obtained

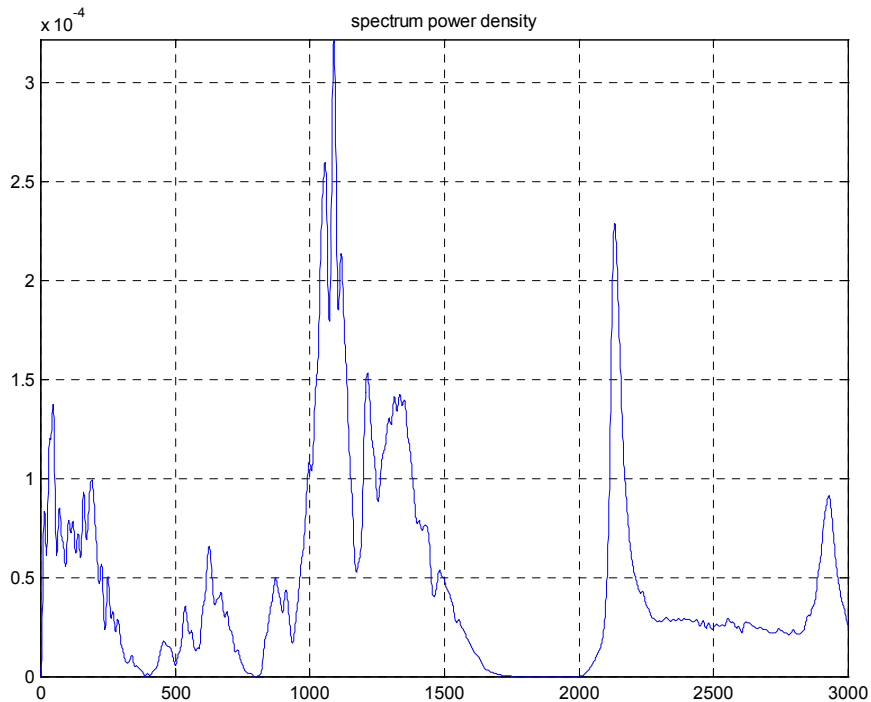


Fig. 29

This spectrum, and the equivalent obtained from the other signals, contains the vibration of the block itself and the contribution of the floor oscillation. The aim is to evaluate if the first natural frequency is similar to the target one (30hz) or the presence of the block mass moved this frequency towards a region that can influence severity indices evaluation.

In the following figures the lower part of the spectrums obtained in different test is reported.

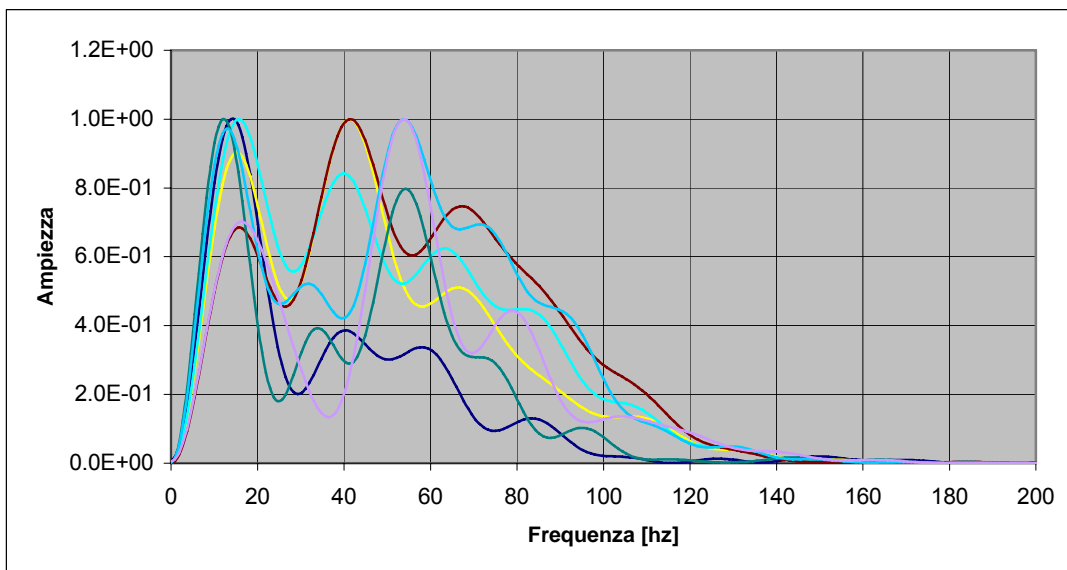


Fig. 30



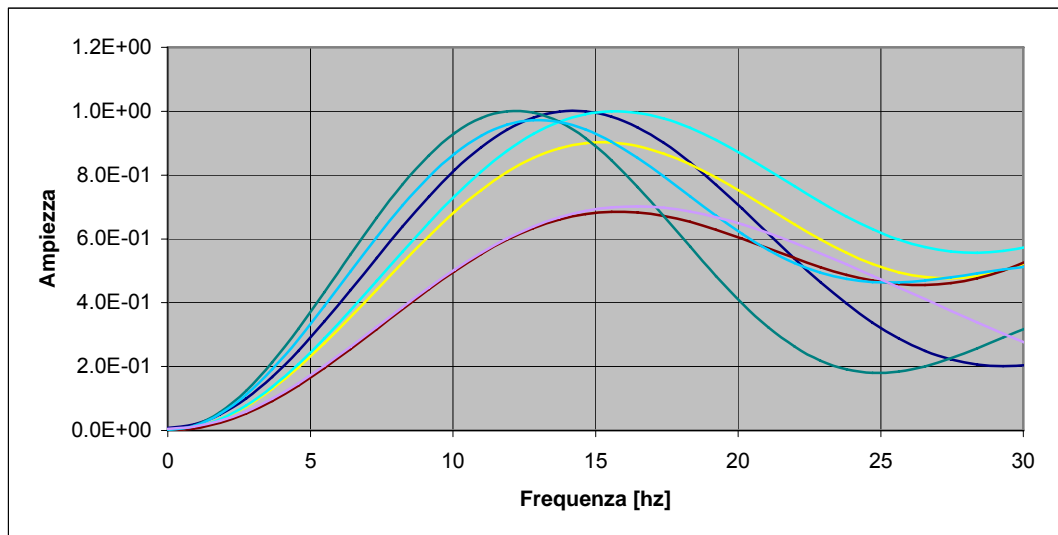


Fig. 31

Can be seen that a the first peak of the spectrum is always located between 10 and 15 hz. The conclusion of the author is that the mass of the mounting block moved the first frequency below 20 hz. In this sense the mass of the mounting block is more important of its stiffness because, being installed to a structure made of thin metal sheet (about .8 mm), influenced the first frequency. Moreover this frequency shift is really important because is not natural (the first frequency should be above 30 hz) and could give a strong contribution during severity indices evaluation (the Asi value is computed using a 50 ms moving average technique).

This is a preliminary result and is the starting point for future activities where this influence will be deeply investigated.